Guiding stars for physics beyond SM: Higgs boson and dark matter

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Based on

- W. s. Li, P. f. Yin and S. H. Zhu, Phys. Rev. D **76**, 095012 (2007) [arXiv:0709.1586 [hep-ph]].
- S. H. Zhu, Chin. Phys. Lett. **24**, 381 (2007), arXiv:hep-ph/0601224.
- S. h. Zhu, Phys. Rev. D **75**, 115004 (2007) [arXiv:hep-ph/0701001].
- P.f. Yin and S. h. Zhu, arXiv:hep-ph/0611270.
- S. h. Zhu, Eur. Phys. J. C **47**, 833 (2006) [arXiv:hep-ph/0512055].

Introduction

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- Invisible Higgs boson
- Higgs boson and/or dark matter as the guiding stars!

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    - A: Limit from experiments in which Higgs boson is supposed to be produced directly.
3. Indirect information from quantum fluctuations and screening theorem: precision observables are only sensitive to log(mH) for leading quantum fluctuation effects.
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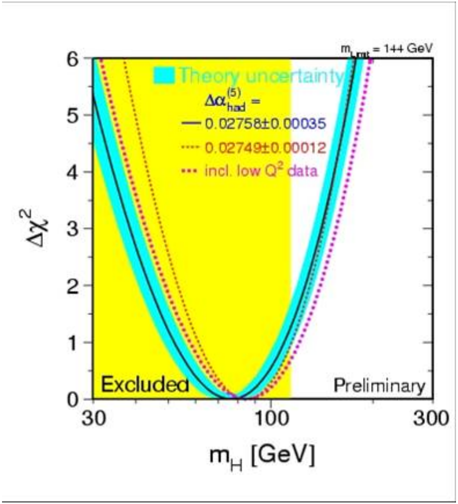
Consistent of direct and indirect limits?



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- What is the meaning of 'invisible decay'?
- For modern detectors, some particles which do not interact with the detector will appear as invisible signal, for example neutrino in the SM.
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- Besides dark matter, the Higgs boson can be invisible due to other reasons (see next part)!

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The investigation on Higgs boson and/or dark matter can provide crucial information for deepening our understanding of the nature!

Invisible SM-like Higgs boson due to X(214) and analysis fault

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- HyperCP three events
- A new pseudoscalar X(214 MeV)?
- All about X(214)
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- Because the SM is extremely success, the existence of one 'SM-like' Higgs boson is the simplest way to coincide the data.
- Other crazy scenarios are, of course, allowed!

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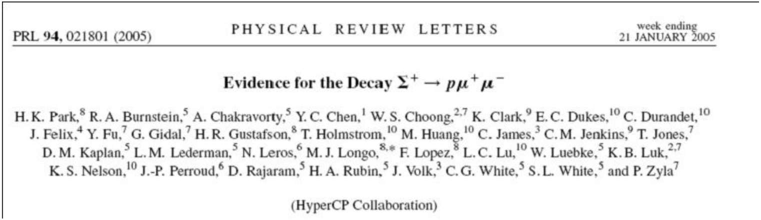
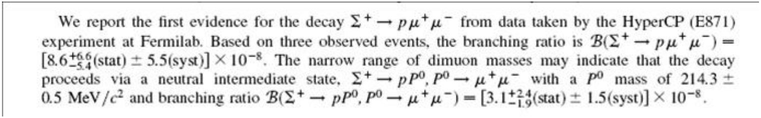


PRL **94,** 021801 (2005) PHYSICAL REVIEW LETTERS week ending 21 JANUARY 2005

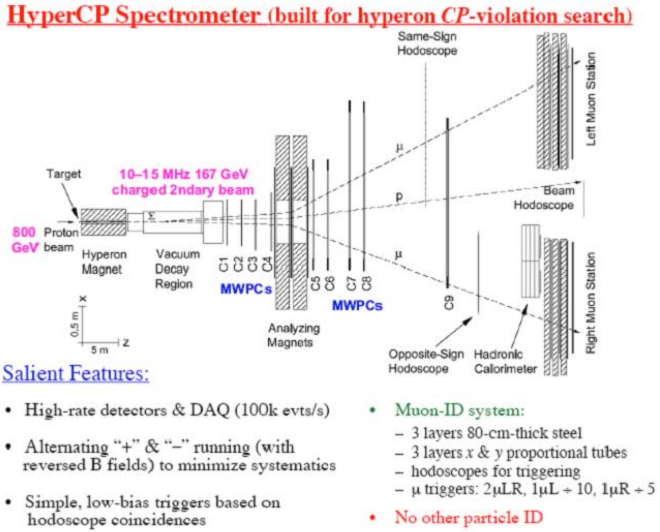
Evidence for the Decay $\Sigma^+ \to p\mu^+\mu^-$

H. K. Park,[8] R. A. Burnstein,[5] A. Chakravorty,[5] Y. C. Chen,[1] W. S. Choong,[2,7] K. Clark,[9] E. C. Dukes,[10] C. Durandet,[10] J. Felix,[4] Y. Fu,[7] G. Gidal,[7] H. R. Gustafson,[8] T. Holmstrom,[10] M. Huang,[10] C. James,[3] C. M. Jenkins,[9] T. Jones,[7] D. M. Kaplan,[5] L. M. Lederman,[5] N. Leros,[6] M. J. Longo,[8,*] F. Lopez,[8] L. C. Lu,[10] W. Luebke,[5] K. B. Luk,[2,7] K. S. Nelson,[10] J.-P. Perroud,[6] D. Rajaram,[5] H. A. Rubin,[5] J. Volk,[3] C. G. White,[5] S. L. White,[5] and P. Zyla[7]

(HyperCP Collaboration)



We report the first evidence for the decay $\Sigma^+ \to p\mu^+\mu^-$ from data taken by the HyperCP (E871) experiment at Fermilab. Based on three observed events, the branching ratio is $\mathcal{B}(\Sigma^+ \to p\mu^+\mu^-) = [8.6^{+6.6}_{-5.4}(\text{stat}) \pm 5.5(\text{syst})] \times 10^{-8}$. The narrow range of dimuon masses may indicate that the decay proceeds via a neutral intermediate state, $\Sigma^+ \to pP^0, P^0 \to \mu^+\mu^-$ with a P^0 mass of 214.3 ± 0.5 MeV$/c^2$ and branching ratio $\mathcal{B}(\Sigma^+ \to pP^0, P^0 \to \mu^+\mu^-) = [3.1^{+2.4}_{-1.9}(\text{stat}) \pm 1.5(\text{syst})] \times 10^{-8}$.



HyperCP Spectrometer (built for hyperon *CP*-violation search)

Salient Features:

- High-rate detectors & DAQ (100k evts/s)
- Alternating "+" & "–" running (with reversed B fields) to minimize systematics
- Simple, low-bias triggers based on hodoscope coincidences

- Muon-ID system:
  - 3 layers 80-cm-thick steel
  - 3 layers x & y proportional tubes
  - hodoscopes for triggering
  - μ triggers: $2\mu LR$, $1\mu L \div 10$, $1\mu R \div 5$
- No other particle ID

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- C. Q. Geng and Y. K. Hsiao, Phys. Lett. B **632**, 215 (2006) [arXiv:hep-ph/0509175].
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X(214) is *not*

- Scalar
- Vector

However X(214) can be pseudoscalar or axial vector!

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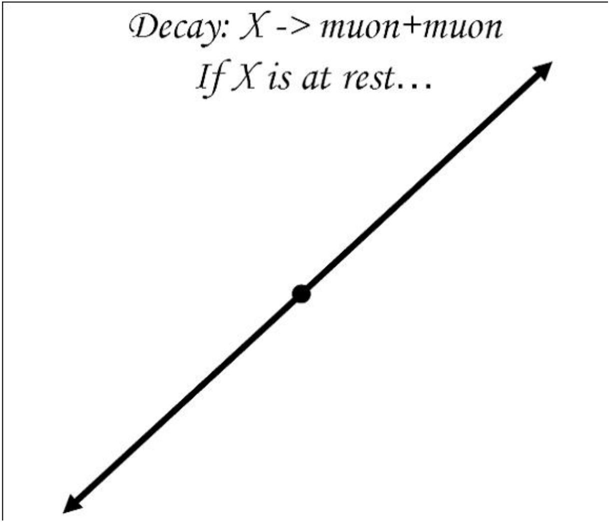
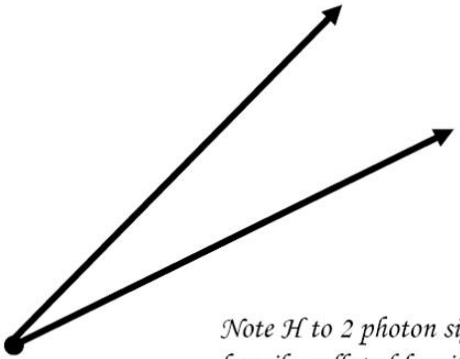
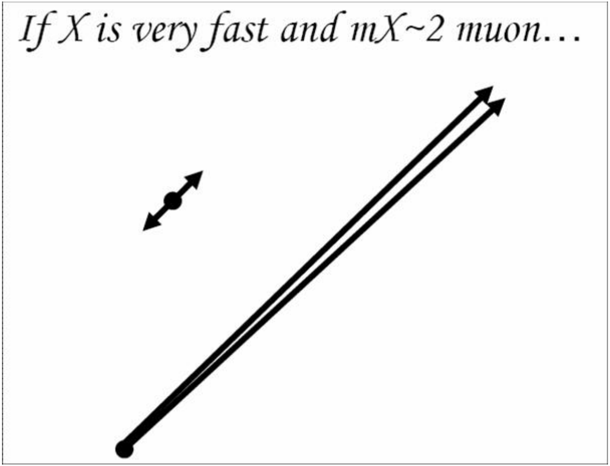
- $m_X = 214.3 \pm 0.5$ MeV
- Dominantly decays into $\mu^+\mu^-$, not photons
- $\Delta m \equiv m_X - 2m_\mu \approx 3$ MeV
- Likely neglected for past experiments, LEP, Tevatron etc.
- Reasons...


Decay: X -> muon+muon
If X is at rest...

If X is very fast…



Note H to 2 photon signal is heavily polluted by pi0 to 2 photons at LHC for this reason!


If X is very fast and mX~2 muon…

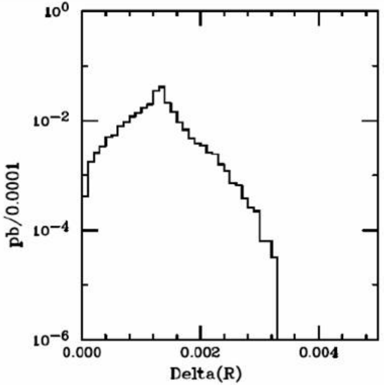


FIG. 1: Distribution of ΔR between $\mu^+\mu^-$ at Tevatron for signal $gg \to h \to aa \to 4\mu$ with "Tevatron basic cuts" of Eq. (4). In all figures of this paper, $m_h = 120$ GeV and $m_a = 0.215$ GeV, except indicated otherwise. The solid (dashed) lines in all figures represent signal (background).

- $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$ approaches 0 due to the tiny $\Delta m \equiv m_X - 2m_\mu$
- At ATLAS, $\Delta R > 0.01$ is applied in order to suppress fake muon and separate different tracks!
- Similar at other detectors!
- X will be missing due to analysis method!
- Fortunately X(214) can be identified at modern detectors, like CMS at LHC, due to the strong magnetic field.

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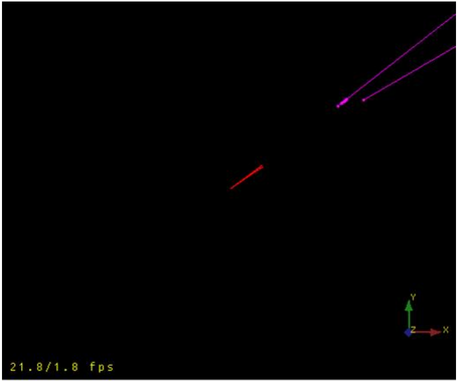
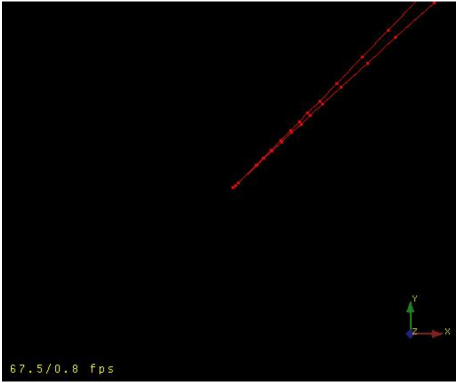


Event $(X \to \mu^+\mu^-)$ view at CMS detector by Z.C. Yang of Peking University!


Y
Z
X
67.5/0.8 fps

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SM-like Higgs boson may decay dominantly into a pair of X(214)

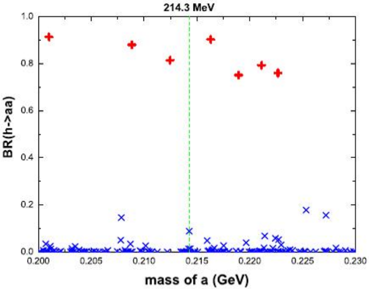

FIG. 1: BR($h \to aa$) as a function of m_a in the NMSSM with $\tan\beta = 30 \sim 60$, $|\mu| = 100 \sim 300$ GeV , $A_t = 1500$ GeV, $M_{SUSY} = 1000$ GeV and $M_{1,2,3} = 100, 300, 500$ GeV. The $+(\times)$ points indicate $m_h < 114 (> 114)$ GeV.

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- What determines the dark matter mass?
- Singlet scalar as the dark matter: the model
- Correlation between SM-like Higgs boson and dark matter
- Invisible SM-like Higgs boson decay
- Other supports
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- We require the theory to be renormalizable, thus naturally take the singlet scalar as the dark matter
- Lagrangian is written as

$$L = L_{SM} + \frac{1}{2}\partial_\mu S \partial^\mu S - \frac{\lambda_S}{4} S^4 - \lambda S^2 (\Phi^+ \Phi)$$

- L_{SM} is the Lagrangian of the SM and Φ is the weak doublet Higgs field. L is obviously invariant under discrete transformation $S \to -S$, which ensures S the good candidate of cold dark matter.

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- After electro-weak symmetry breaking $< \Phi >= v = 246$ GeV, the Higgs boson, as in the standard model,

$$m_h^2 = \lambda_h v^2$$

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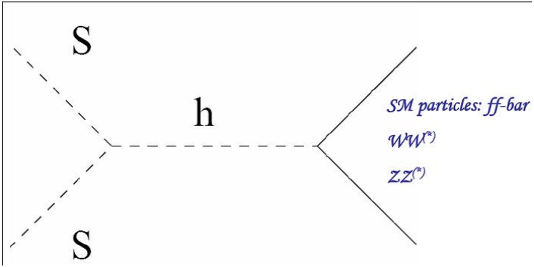

Schematic Feynman diagram for $SS \rightarrow$ SM particles. Here f and V represent SM fermions and weak gauge bosons respectively.

- The current relic density of S can be written as

(C. P. Burgess, M. Pospelov and T. ter Veldhuis, Nucl. Phys. B **619**, 709 (2001))

$$\Omega_S h^2 = \frac{(1.07 \times 10^9) x_f}{\sqrt{g_*} M_{pl} [\text{in GeV}] < \sigma v_{rel} >},$$

where g_* counts the degrees of freedom in equilibrium at annihilation, x_f is the inverse freeze-out temperature in units of m_S, which can be obtained by solving the equation

$$x_f \simeq \ln \left[\frac{0.038 M_{pl} m_S < \sigma v_{rel} >}{\sqrt{g_* x_f}} \right].$$

- Here v_{rel} is the relative velocity of the two incoming dark matter particles, M_{pl} is the Planck mass and $< ... >$ denotes the relevant thermal average.
- σv_{rel} is

$$\begin{aligned}\sigma_{ann} v_{rel} &= \frac{8\lambda^2 v^2}{(4m_S^2 - m_h^2)^2 + m_h^2\Gamma_h^2} F_X \\ &= \frac{8m_S^4}{v^2\left[(4m_S^2 - m_h^2)^2 + m_h^2\Gamma_h^2\right]} F_X \qquad (1)\end{aligned}$$

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- Here

$$F_X = \lim_{m_{\tilde{h}} \to 2m_S} \left(\frac{\Gamma_{\tilde{h}\to X}}{m_{\tilde{h}}} \right). \qquad (2)$$

- Γ_h is the Higgs total decay width and $\Gamma_{\tilde{h}\to X}$ denotes the partial decay width for the virtual $\tilde{h}$ decay into X, $\tilde{h} \to X$, in the limit $m_{\tilde{h}} \to 2m_S$. Here X represents SM particles.
- Relic density (within 3σ uncertainty)

$$0.093 < \Omega_{dm} h^2 < 0.129$$

where $h \approx 0.71$ is the normalized Hubble expansion rate.

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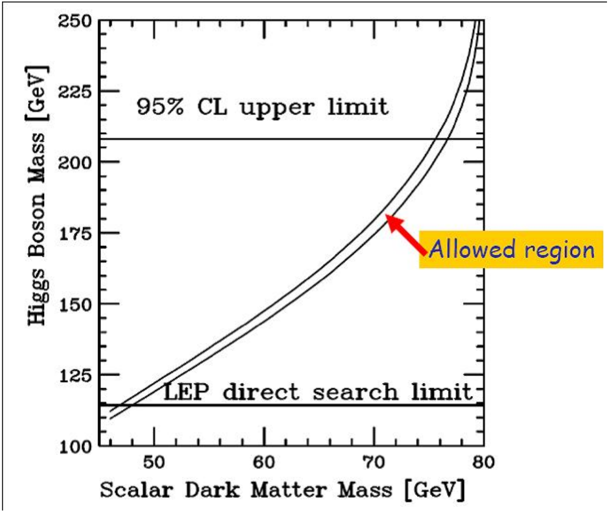
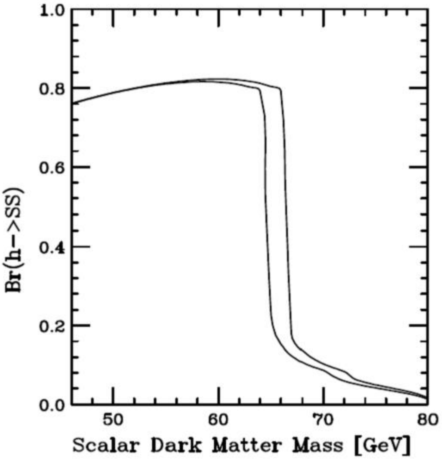

250
225
200
175
150
125
100
Higgs Boson Mass [GeV]
95% CL upper limit
Allowed region
LEP direct search limit
50
60
70
80
Scalar Dark Matter Mass [GeV]

m_S [GeV]	m_h upper limit [GeV]	m_h lower limit [GeV]
50	122	119
55	134	131
60	148	144
65	162	158
70	180	174
75	204	197
80	275	261

Table: Upper and lower limits on Higgs boson for several m_S in order to obtain the correct relic abundance.

Correlation between masses of SM-like Higgs boson and (singlet) scalar dark matter

- What determines the dark matter mass?
- Singlet scalar as the dark matter: the model
- Correlation between SM-like Higgs boson and dark matter
- Invisible SM-like Higgs boson decay
- Other supports
- Pause


Br(h−>SS)
1.0
0.8
0.6
0.4
0.2
0.0
50
60
70
80
Scalar Dark Matter Mass [GeV]

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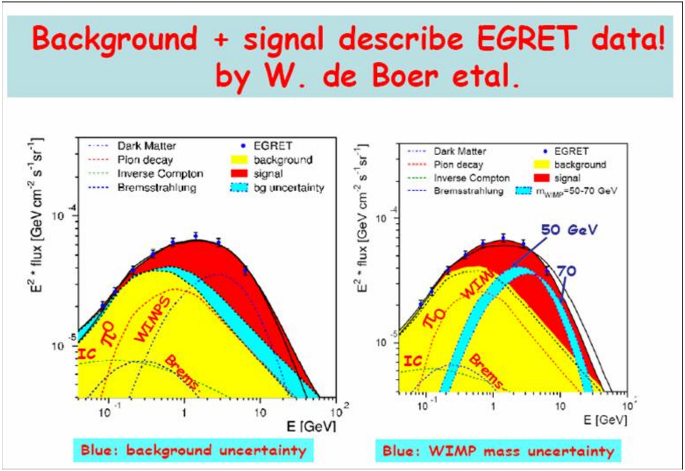
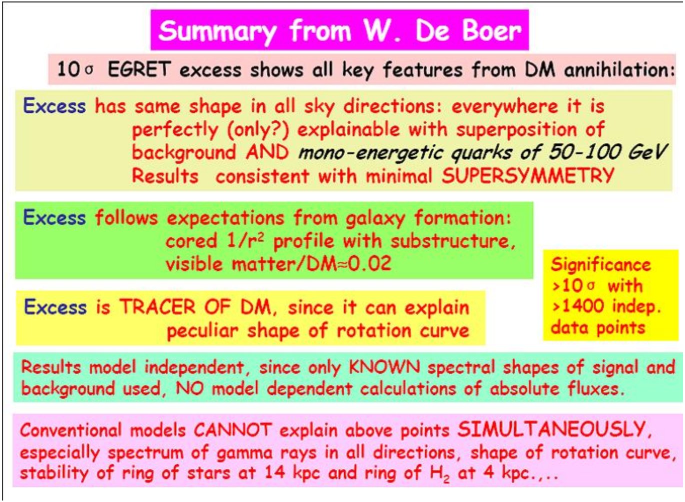


Background + signal describe EGRET data!
by W. de Boer etal.

Blue: background uncertainty

Blue: WIMP mass uncertainty



Summary from W. De Boer

10σ EGRET excess shows all key features from DM annihilation:

Excess has same shape in all sky directions: everywhere it is perfectly (only?) explainable with superposition of background AND *mono-energetic quarks of 50-100 GeV*
Results consistent with minimal SUPERSYMMETRY

Excess follows expectations from galaxy formation: cored $1/r^2$ profile with substructure, visible matter/DM≈0.02

Excess is TRACER OF DM, since it can explain peculiar shape of rotation curve

Significance $>10\sigma$ with >1400 indep. data points

Results model independent, since only KNOWN spectral shapes of signal and background used, NO model dependent calculations of absolute fluxes.

Conventional models CANNOT explain above points SIMULTANEOUSLY, especially spectrum of gamma rays in all directions, shape of rotation curve, stability of ring of stars at 14 kpc and ring of H_2 at 4 kpc.,..

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- The Higgs boson is light and may decay dominantly into (~ 60 GeV)DM.
- Detecting invisible Higgs boson at LHC and ILC!

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L-R models (For a review to see, R. Mohapatra, 'Unification and Supersymmtry')

- Parity is restored at energy scale higher than weak interaction (represented by $m_W \sim 100$ GeV)
- Predict generically W_R and Z_R which are non-singlet fields for right-handed usual SM fermions.
- Gauge structure other than the SM one has not been experimentally established. On the contrary, W_R has been pushed up to 1.6TeV or higher in minimal L-R model.
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- Parity is restored in a general sense, as originated in Lee-Yang’ s 1956 paper
- Current experiments disfavor the case that mirror particles are non-singlet under SM gauge group.
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Okun said: “Mirsy (mirror symmetry) cannot compete with SUSY in the depth of its concept and mathematics. But I believe it can compete in the breadth and diversity of its phenomenological predictions. Certainly, mirror matter is richer than the dark matter of SUSY”

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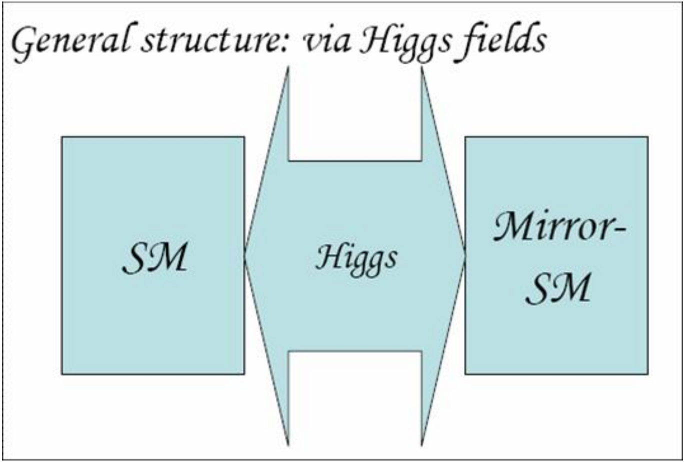
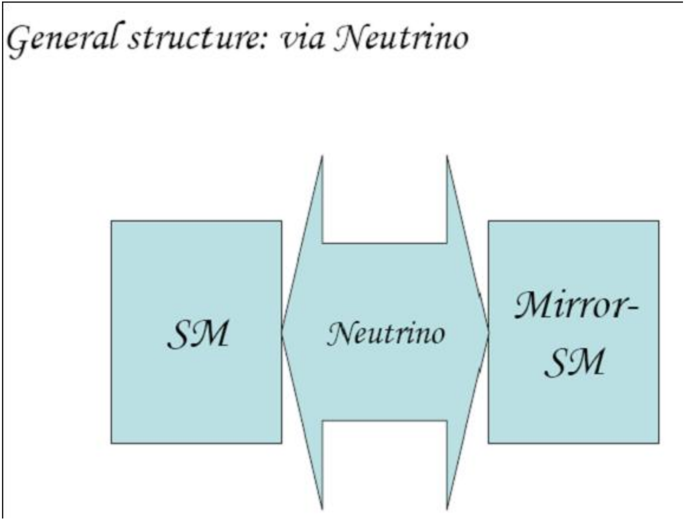
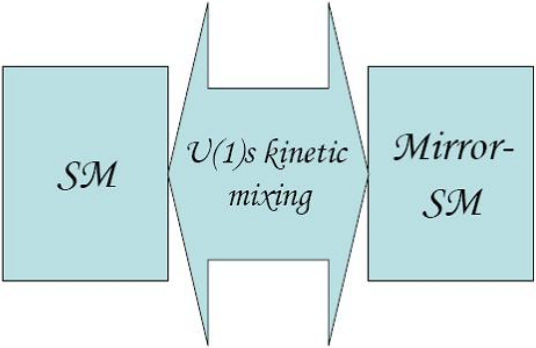

General structure: via Higgs fields
SM
Higgs
Mirror-SM



General structure: via Neutrino

General structure: via U(1)s kinetic mixing



SM

U(1)s kinetic mixing

Mirror-SM

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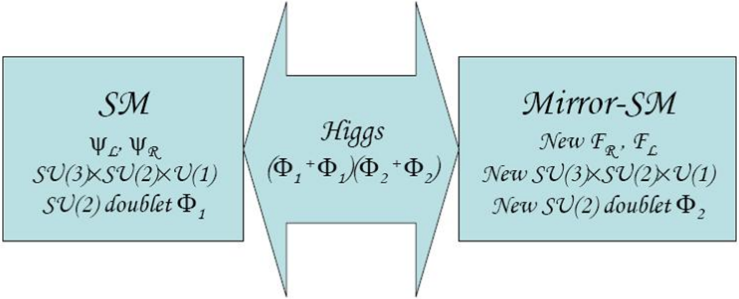
R. Foot, H. Lew and R. R. Volkas, PLB(1991)



- The minimal gauge group of the new mirror model is $G_{SM} \otimes G' = SU(3) \otimes SU(2) \otimes U(1) \otimes SU(3)' \otimes SU(2)' \otimes U(1)'$.
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- The gauge quantum numbers under $G_{SM} \otimes G'$ for the usual and mirror fermion fields are

$$\begin{array}{rcl}
L_L^i \sim (1,2,-1)(1,1,0) & , & (L_R')^i \sim (1,1,0)(1,2,-1) \\
e_R^i \sim (1,1,-2)(1,1,0) & , & (e_L')^i \sim (1,1,0)(1,1,-2) \\
Q_L^i \sim (3,2,\frac{1}{3})(1,1,0) & , & (q_R')^i \sim (1,1,0)(3,2,\frac{1}{3}) \\
u_R^i \sim (3,1,\frac{4}{3})(1,1,0) & , & (u_L')^i \sim (1,1,0)(3,1,\frac{4}{3}) \\
d_R^i \sim (3,1,-\frac{2}{3})(1,1,0) & , & (d_L')^i \sim (1,1,0)(3,1,-\frac{2}{3})
\end{array}$$

with i the family index.

- The Z_2 parity symmetry that we define now is

$$\begin{aligned} \vec{r} \leftrightarrow -\vec{r}, t \leftrightarrow t, &\quad G^\mu \leftrightarrow G'_\mu \\ W^\mu \leftrightarrow W'_\mu, B^\mu \leftrightarrow B'_\mu & \\ L_L \leftrightarrow L'_R, e_R \leftrightarrow e'_L, &\quad Q_L \leftrightarrow Q'_R, \\ u_R \leftrightarrow u'_L, d_R \leftrightarrow d'_L. & \end{aligned}$$

- One of the advantages of this model is that there are natural candidates of non-baryonic dark matter in addition to restore parity.
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- One assumes that the Higgs potential is invariant under the discrete symmetry $\phi_1 \longrightarrow \phi_2$ to keep the parity in a broader sense.
- The Higgs potential is very simply given by

$$\begin{aligned} V(\phi_1,\phi_2) &= -\mu^2\left(\phi_1^\dagger\phi_1+\phi_2^\dagger\phi_2\right) \\ &+ \lambda\left(\phi_1^\dagger\phi_1+\phi_2^\dagger\phi_2\right)^2 \\ &+ \eta\phi_1^\dagger\phi_1\phi_2^\dagger\phi_2. \end{aligned} \tag{3}$$

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After electro-weak symmetry breaking, the Higgs fields can be written as

$$\phi_i = \left(\begin{array}{c} \varphi_i \\ \frac{1}{\sqrt{2}}(v_i + H_i + \chi_i) \end{array} \right), \tag{4}$$

where $\varphi_i^\dagger, \chi_i$ are Goldstone bosons, which will be absorbed by corresponding gauge fields.

The vacuum may not be invariant under Z_2 transformation although the Higgs potential is invariant under this discrete transformation. In fact there are two ways of spontaneous symmetry breaking, depending on the choice of the sign of η

(R. Foot, H. Lew, R. R. Volkas, JHEP **032**, 0007 (2000)).

$\eta < 0$: symmetric vacua:

- Vacuum is invariant under transformation $\phi_1 \leftrightarrow \phi_2$.

$$v^2 = v_1^2 = v_2^2 = \frac{2\mu^2}{4\lambda + \eta}. \tag{5}$$

- Define Higgs boson mass eigenstates as H, h (assume H is heavier than h),

$$H_1 = \frac{1}{\sqrt{2}}(H + h) \tag{6}$$

$$H_2 = \frac{1}{\sqrt{2}}(H - h). \tag{7}$$

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- The Higgs boson mass can be expressed as

$$\begin{aligned} m_H^2 &= (4\lambda + \eta)v^2 && (8) \\ m_h^2 &= -\eta v^2. && (9) \end{aligned}$$

$\eta > 0$: non-symmetric vacuum:

- Requiring the minimum of Higgs potential is stable, then

$$ {v_1}^2 = \frac{\mu^2}{\lambda}, {v_2}^2 = 0. \tag{10} $$

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- It seems that all the mirror particles must be massless. However mirror particle can obtain tiny mass through mirror QCD condensation, but we don't discuss this case further.

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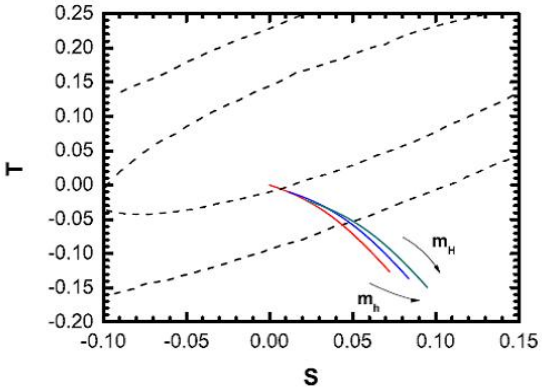

FIG. 1: The ellipses indicate the regions in the S, T plane which are allowed by EWPO at 1σ (68%) and 2σ (95%) level respectively [20]. Three curves represent three different m_h at 115, 150 and 200 GeV, and m_H increases from $100 \sim 1000$ GeV for each curve.

Lighter Higgs boson (h) decay

$$\begin{aligned} & Br(h \to b\bar{b}) \\ = & \frac{\Gamma(h \to b\bar{b})}{\Gamma(h \to SM) + \Gamma(h \to Mirror)} \\ = & \frac{1}{2} Br(h_{SM} \to b\bar{b}), \end{aligned} \tag{12}$$

Heavier Higgs boson (H) decay

$$
\begin{aligned}
& Br(H \to hh)\left[Br(H \to b\bar{b})\right] \\
= & \frac{\Gamma(H \to hh)\left[\Gamma(H \to b\bar{b})\right]}{\Gamma(H \to SM) + \Gamma(H \to Mirror) + \Gamma(H \to hh)} \\
= & \frac{\Gamma(H \to hh)\left[\Gamma(H \to b\bar{b})\right]}{2\Gamma(H \to SM) + \Gamma(H \to hh)}.
\end{aligned}
\qquad (13)
$$

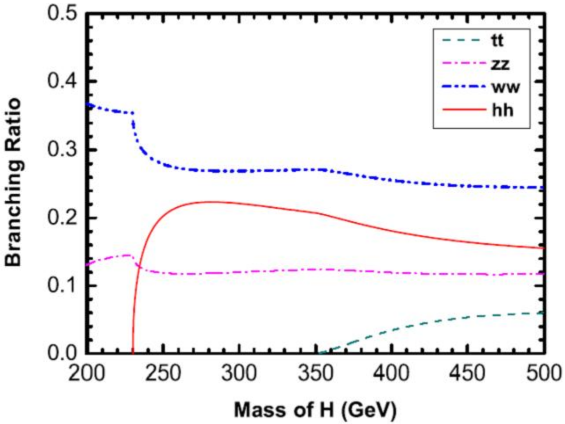

FIG. 2: Branching ratios of H as a function of m_H, where $m_h = 115\text{GeV}$.

Higgs bosons production

- For the case $m_H < 2m_h$, each Higgs boson acts like the SM one except with only half production rate in MM model. Moreover each Higgs boson decays into SM matter with branching ratio half of SM case in MM model.
- For the case $m_H > 2m_h$, new decay channel opens up. Thus provides unique signal to investigate such model. (We focus on this scenario!)

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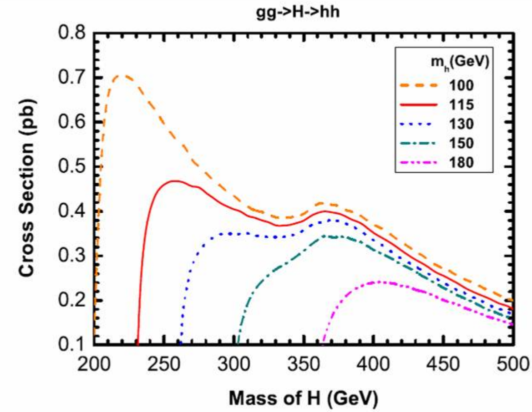

FIG. 4: Cross sections [in pb] of $gg \to H \to hh$ as a function of m_H at the LHC,where $m_h = 100, 115, 130, 150$ and 180 GeV from top to bottom .

Detail simulation for $p\,p \to g\,g \to H \to h(\to b^+b^-) + h_{inv}$

- The most important irreducible background arises from $Zb\bar{b}$ production, where Z decays into neutrinos.
- Moreover QCD multi-jet production, such as $p\,p \to Z(\to \nu\bar{\nu})jj$, are also the sources of the large backgrounds.
- In our analysis we require two b-tagged jets in order to suppress these backgrounds.
- Other backgrounds can arise from ZZ, WZ, $Wb\bar{b}$, single top and $t\bar{t}$ production

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- Other backgrounds can arise from ZZ, WZ, $Wb\bar{b}$, single top and $t\bar{t}$ production

Basic cuts:

$$P_T(j_1), P_T(j_2) > 20GeV, 15GeV \tag{14}$$

$$|\eta_j| < 2 \tag{15}$$

$$\triangle R(jj) > 0.4 \tag{16}$$

$$m_{jj} > 10GeV, \tag{17}$$

To suppress the backgrounds from $Wb\bar{b}$, WZ, single top with $t \to bW$ and $t\bar{t} \to bW\bar{b}W$. For these backgrounds, the final state charge leptons or jets from W escape from the detection. We suppress these contributions by vetoing events from W decay with follow cuts

$$P_T(j) > 15GeV, |\eta(j)| < 2.0 \tag{18}$$

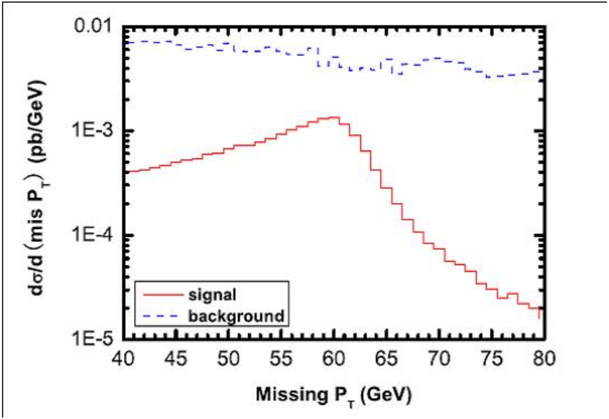
$$P_T(l^\pm) > 10GeV, |\eta(l^\pm)| < 2.5 \tag{19}$$

The numerical results after imposing cuts Eqs. 14-19

Channel	$Zb\bar{b}$	$Zb\bar{c}$	Zbj	$Zc\bar{c}$	Zcj	Zjj
$\sigma(pb)$	3.250	0.011	0.107	0.001	0.027	0.063
Channel	ZZ	$W^-b\bar{b}$	W^-Z	$t\bar{b}$	$t\bar{t}$	
$\sigma(pb)$	0.072	0.417	0.032	0.017	0.346	

Table: The cross sections (in pb) of backgrounds for $b\bar{b}+ \not{P}_T$ after basic kinematical cuts Eqs. 14-19 and tagging efficiencies where $j = u, \bar{u}, d, \bar{d}, s, \bar{s}, g$.

The signals and backgrounds for $b\bar{b}+ \not{P}_T$ as a function of $\not{P}_T$

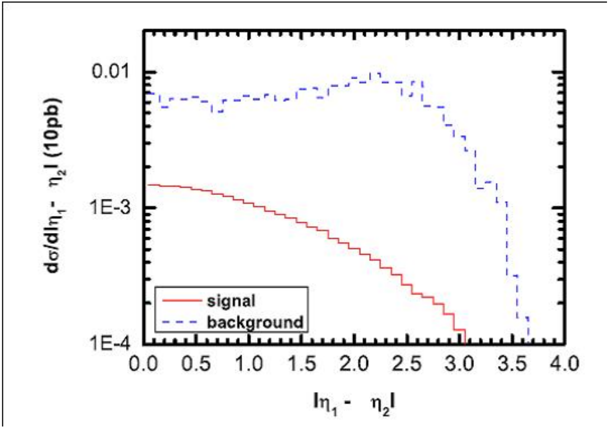


In order to suppress the backgrounds, we impose the further cuts as following

$$|m_{jj} - m_h| < 15GeV \tag{20}$$

$$40GeV < \not{P}_T < 80GeV. \tag{21}$$

The signals and backgrounds as the function of $|\eta_{j_1} - \eta_{j_2}|$



We require

$$|\eta_{j_1} - \eta_{j_2}| < 1.5, \tag{22}$$

and this cut would improve significance of the signals by a factor of 1.2.

In order to suppress the largest $Zb\bar{b}$ background, we can utilize the precise measurement of $Z(\to \mu^+\mu^-)b\bar{b}$.

$$\sigma_{bkg}^{Zb\bar{b},imp} = \sigma_{bkg}^{Zb\bar{b}} - R \times \sigma_{b\bar{b}\mu^+\mu^-}. \tag{23}$$

In Eq. 23, $\sigma_{b\bar{b}\mu^+\mu^-}$ is the cross section for $Z(\to \mu^+\mu^-)b\bar{b}$ production which adopts the same kinematical cuts for $Z(\to \nu\bar{\nu})b\bar{b}$.

R is a ratio which is defined as

$$R = \frac{\sum_i Br(Z \to \nu_i \bar{\nu}_i)}{Br(Z \to \mu^+ \mu^-)}, \tag{24}$$

and in our case $R = 5.94$. Note that $\sigma_{bkg}^{Zb\bar{b},imp} \approx 0$ if we can measure all final states $b\bar{b}\mu^+\mu^-$ in any kinematical region.

Cuts	$s(fb)$	$b(fb)$	S/B	$S/\sqrt{B_1}$	$S/\sqrt{B_2}$
basic cuts	26.6	4948	0.0054	1.19	2.07
$\|m_{jj} - m_h\| < 30$GeV	26.6	1133	0.023	2.50	4.32
$\|m_{jj} - m_h\| < 15$GeV	26.6	492	0.054	3.79	6.56
$20 < \not{P}_T < 120$GeV	25.0	401	0.062	3.94	6.83
$40 < \not{P}_T < 80$GeV	19.4	202	0.096	4.33	7.49
$\|\eta_{j_1} - \eta_{j_2}\| < 1.5$	15.2	95	0.16	4.93	8.54
improved backg	15.2	18	0.83	11.4	19.8

Table: The significance $S/\sqrt{B_1}$ is for the luminosity of $10 fb^{-1}$ and $S/\sqrt{B_2}$ is for the luminosity of $30 fb^{-1}$. Here $m_H = 260$ GeV and $m_h = 115$ GeV.

	$m_h = 100$GeV	$m_h = 115$GeV	$m_h = 130$GeV
$m_H = 250$ GeV	8.2(40,80)	8.3(10,60)	$--$
$m_H = 300$ GeV	9.0(80,130)	9.6(60,110)	17.5(40,80)
$m_H = 350$ GeV	5.5(100,150)	6.6(90,140)	11.6(80,120)

Table: The integrated luminosity [in fb^{-1}], which is required to observe $H \to hh \to b\bar{b} + \not{P}_T$ with 5σ significance at the LHC. The numbers in bracket are mass window of $\not{P}_T$. Note the Eq. 23 is not applied.

Detail simulation for $gg \to H \to hh \to 4b$.

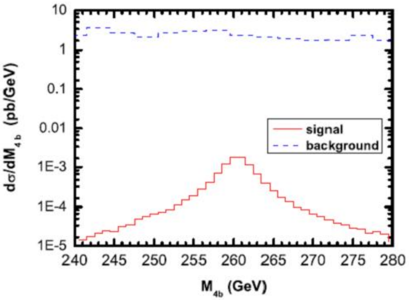


FIG. 7: The distributions of the signals and backgrounds for $b\bar{b}b\bar{b}$ as a function of invariant mass for $4b$ after applying cuts (see text) and tagging efficiencies.

Conclusion and discussion

- Provided that there are physics beyond the SM, we find them *likely* via the investigation on Higgs boson(s) and/or dark matter.
- The importance of combination of cosmology and particle physics.
- The coming LHC may/should open the new chapter of particle physics!

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Thanks for your attention!